

HYBRID POWER SYSTEM FOR CONTINUOUS RELIABLE POWER
AT LOCATIONS INCLUDING REMOTE LOCATIONS

BACKGROUND OF THE INVENTION

1. Technical Field

This invention relates to a method and apparatus for producing power, and more particularly, to a method and apparatus for producing ultra-reliable power with redundancy which requires little maintenance or supervision and with improved fuel consumption.

2. Background of the Invention

The requirements for reliable power supply are more and more stringent with the advance of modern industry, computer and telecommunications systems and with the increasing costs of non-supply electricity. This particularly applies for on-site generation of electricity, be it for grid connected and distributed generation or off-grid prime power supply at remote locations. The conventional solutions for providing high efficiency on-site generation of electricity include, for short periods of interruption, battery or flywheel uninterruptible power supply (UPS) systems are used; and for longer periods, engine driven generators such as diesel generators are used for both applications relying on grid power, as well as for distributed generation and off-grid applications. The short term standby power using batteries

has a distinct disadvantage when failures occur. This is especially true since there is no satisfactory diagnostic system to detect failures of batteries on standby: a single cell failure can cause failure of the whole battery pack. Expensive climate control and limited life are also drawbacks of battery systems. In addition, while flywheel systems do not have the diagnostic problem, the systems can support the load for even less time than the battery systems.

The diesel generators used for longer periods of standby operation, however, have problems of unreliable startups and require frequent maintenance and periodic overhaul. Fuel cells and stirling engines can also be used but fuel cells have too long of a startup process and these systems are still in the development stage and have no proven reliability.

Combined cycle power plants, on the other hand, i.e., a power plant having usually a gas turbine and a bottoming cycle power generating unit, have a quite high overall efficiency since heat contained in the exhaust gases of the primary power generating unit is utilized in the bottoming cycle power generating unit to produce electric power. However, the reliability of such systems can be questionable. For example, see the article "Raising the Reliability of Advanced Gas Turbines", Vol. Power, Vol. 146, No. 2, March/April 2002, which reports that there are several reliability issues that need to be addressed when using combined cycle power plants.

For power generation systems that supply remote telecommunications with high reliable off-grid power, several options are available including: multiple diesel generators (MDG), photovoltaics, photovoltaics combined with diesel generators, thermoelectric generators (TEG), and closed cycle vapor turbogenerators (CCVT).

Multiple diesel generators (MDG) with one generator operating and one or two generators on standby has an advantage in that these systems have low fuel consumption and can operate using liquid or gaseous fuel. A multiple diesel generator system, however, depends on the reliability of the start-up of a standby generator if the operating generator fails. This necessitates a large battery to be included in the system so that it can be used in the event that the standby generator does not start. Further, the included large batteries typically require climate control in the form of heating or air conditioning, thus increasing the complexity and fuel consumption of the system for a given load.

In photovoltaic systems, batteries are used to compensate for the hours/days without solar radiation. Batteries in photovoltaic systems are usually quite large and work on deep discharge cycles. Because of the deep discharge cycles nickel-cadmium are better suited in photovoltaic systems than lead acid batteries. The cost of nickel-cadmium batteries is very high. In addition to the high cost of batteries, the life-span of these batteries is usually less

than 10 years. Maintenance, vandalism and theft of the batteries of photovoltaic are additional concerns for photovoltaic systems.

Photovoltaic systems having a diesel generator back-up share the same problems as the previously-mentioned strictly photovoltaic systems, namely, cost, life-span and maintenance of batteries as well as risk of vandalism and theft. In addition, utilizing a diesel generator as a back-up power source can produce reliability issues as the system redundancy depends on an unreliable diesel engine start.

As far as thermoelectric generators (TEG) are concerned, the TEG system has the highest fuel consumption of any of the systems thus far discussed. The high fuel consumption is aggravated by the fact that a TEG system is a constant power device that requires a dummy load for dissipating any excess energy and, thus requiring additional fuel consumption due to the over-sizing of the unit, output variations due to ambient conditions or varying load requirements. If additional batteries are not used, the battery will not be properly charged and will require additional maintenance and manual charging during maintenance and thus the life span of the battery will decrease. Additionally, TEG systems have a high fuel consumption and the life span of a TEG system is typically less than 10 years.

A more recent development in providing reliable power to remote locations has been the introduction of fuel cells. A fuel

cell is an energy conversion device that generates electricity and heat by electrochemically combining a gaseous fuel and an oxidant gas via an ion conducting electrolyte. The main characteristic of a fuel cell is its ability to convert chemical energy directly into electrical energy without the need for heat conversion (i.e., converting heat to electric or mechanical power optimized in accordance with the Second Law of Thermodynamics), giving much higher conversion efficiencies than heat engines (e.g., engine generators, CCVTs or TEGs). A system having such fuel cells and a gas turbine for achieving high efficiencies has been proposed by Siemens Westinghouse, as indicated in their website. However, the fuel cell technology is not mature and the life and reliability of the fuel cells are not sufficient to maintain reliable remote power without a proven backup for when the fuel cell fails.

Finally, the closed cycle vapor turbogenerator (CCVT) systems have a fuel consumption which, although lower than the TEG system, is much higher than that of a diesel generator. Redundancy for these systems is usually achieved through the use of one or two operating CCVTs; with one CCVT on warm standby. Fuel consumption varies in accordance with the load but the use of two CCVT each operating at half load consumes 20% more fuel than one load at 100% load. Usually the level of power production in remote locations is between 1 - 10 kW.

U.S. Patent No. 4,590,384, the disclosure of which is hereby

incorporated by reference, discloses a peak shaving power plant for utilizing a source of low grade heat comprising a Rankine cycle turbine having an organic working fluid utilizing heat from a low grade heat source, a generator driven by the turbine and having a generating capacity in excess of the capacity of the turbine, and a fast starting prime mover, such as an internal combustion engine, having a capacity that is less than the generating capacity of the generator. A selectively operable coupling connects the output of the fast starting prime mover to the generator so that, on demand, the fast starting prime mover can drive the generator providing peak power shaving in the amount of the capacity of the prime mover.

In U.S. Patent No. 4,982,569, the disclosure of which is hereby incorporated by reference, a hybrid power plant is disclosed and includes an intermittently operable non-fuel consuming power generator, such as a photovoltaic cell array, or a wind generator, connected through a control-circuit to a battery for charging the same during operation of the power generator, and for supplying current to a time-wise, substantially constant, electrical load. In addition, the hybrid power plant includes an electric generator connected to a standby operable prime mover, such as a Rankine cycle organic fluid turbogenerator, for charging the battery and supplying current to the electrical load when the intermittently operable non-fuel consuming power generator is not operating. In

the case of a photovoltaic array, this situation occurs at night so that the prime mover of the hybrid power plant can be started as it becomes dark.

It is therefore an object of the present invention to provide a new and improved method of and apparatus for providing ultra-reliable power wherein the disadvantages of high fuel consumption, unreliability, maintenance, use of batteries and the associated climate control (which increases the power consumption and maintenance, thus reducing the reliability) as outlined above are reduced or substantially overcome.

SUMMARY OF THE INVENTION

The present inventive subject matter is drawn to an apparatus that combines a fuel efficient, but failure prone, primary power generation unit system such as a high temperature fuel cell (e.g., solid oxide fuel cell (SOFC) or molten carbonate fuel cell (MCFC)), an engine generator (diesel or gas fueled, e.g. a diesel engine (DE), a diesel generator (DG), or a gas engine generator (GEG)), a gas turbine generator (operating on gas or liquid fuel, e.g., a gas turbine generator), or a stirling engine (STE), with a secondary power unit that is a very high reliability closed cycle vapor turbine (CCVT) which operates according to a Rankine cycle using steam or organic working fluid that is capable of producing 100% of the electric power that is produced by the primary power unit and

which is heated in hot standby by rejected heat of the primary power unit, whereas the vaporizer of the CCVT is maintained during hot standby at a temperature above its nominal operating temperature and the vapor turbine of the CCVT is preferably maintained at idle during hot standby at a rotating speed above its nominal rotating speed.

The present inventive subject matter is thus drawn to a hybrid ultra reliable power generating system for supplying continuous reliable power at remote locations comprising: a primary power unit producing electric power, such as a high temperature fuel cell (SOFC or MCFC) or an engine generator (DE, DG, or GEG), a gas turbine generator operating on gas or liquid fuel (GTG), or a stirling engine (STE), that is supplied to a load; and a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system, which operates according to a Rankine cycle using steam or organic working fluid, that is capable of producing 100% of the electric power that is produced by the primary power unit and which is heated in hot standby by rejected heat of the primary power unit, wherein the vaporizer of the CCVT is maintained during hot standby at a temperature above its nominal operating temperature and the vapor turbine of the CCVT is preferably maintained at idle during hot standby at a rotating speed above its nominal rotating speed. Preferably, the CCVT includes a burner that combusts the same fuel as the primary power unit and supplies sufficient heat so that the CCVT produces 100% of the power produced by said primary

power unit to the load once the primary power unit stops operation.

The present invention also relates to a method for supplying continuous reliable power at remote locations comprising the steps of: providing a primary power unit producing electric power, such as a high temperature fuel cell (SOFC or MCFC), an engine generator (DE, DG or GEG), a gas turbine generator operating on gas or liquid fuel (GTG), or a stirling engine (STE), that is supplied to a load; and providing a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system which operates according to a Rankine cycle using steam or organic working fluid, that is capable of producing 100% of the electric power that is produced by the primary power unit and which is heated in hot standby by rejected heat of the primary power unit, wherein the vaporizer of the CCVT is maintained during hot standby at a temperature above its nominal operating temperature and the vapor turbine of the CCVT is preferably maintained at idle during hot standby at a rotating speed above its nominal rotating speed. Preferably, the method also includes the step of providing a burner in the CCVT that combusts the same fuel as the primary power unit and supplies sufficient heat so that the CCVT produces 100% of the power produced by said primary power unit to the load once the primary power unit stops operation.

Furthermore, the present inventive subject matter is drawn to an apparatus that combines a fuel efficient primary power generation unit system such as a high temperature fuel cell (e.g.,

molten carbonate fuel cell (MCFC)) with a secondary power unit that is a very high reliability closed cycle vapor turbine (CCVT) which operates according to a Rankine cycle using organic working fluid that is capable of producing approximately 5 - 15% of the electric power that is produced by the primary power unit and which is heated by rejected heat of the primary power unit, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit.

The present inventive subject matter is thus drawn to a hybrid ultra reliable power generating system for supplying continuous reliable power at various locations, e.g. at remote locations, comprising: a primary power unit producing electric power, such as a high temperature fuel cell, e.g. molten carbonate fuel cell (MCFC) that is supplied to a load; and a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system, which operates according to a Rankine cycle using organic working fluid, which is capable of producing approximately 5 - 15% of the electric power that is produced by the primary power unit and which is heated by rejected heat of the primary power unit, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit. By using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit. Preferably, the CCVT includes a burner that combusts the same fuel as the primary power unit and supplies sufficient

heat so that the CCVT continues to produce approximately 5 - 15% of the power produced by said primary power unit to the load once the primary power unit stops operation.

Furthermore, the present invention also relates to a method for supplying continuous reliable power at locations including e.g. remote locations, comprising the steps of: providing a primary power unit producing electric power, such as a high temperature fuel cell (MCFC) that is supplied to a load; and providing a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system which operates according to a Rankine cycle using organic working fluid, which is capable of producing approximately 5 - 15% of the electric power that is produced by the primary power unit and which is heated by rejected heat of the primary power unit, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit. By using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit. Preferably, the method also includes the step of providing a burner in the CCVT that combusts the same fuel as the primary power unit and supplies sufficient heat so that the CCVT continues to produce approximately 5 - 15% of the power produced by said primary power unit to the load once the primary power unit stops operation.

BRIEF DESCRIPTION OF THE DRAWINGS

A description of the present inventive subject matter

including embodiments thereof is presented and with reference to the accompanying drawings, the description is not meant to be considered limiting in any manner, wherein:

Fig. 1 is a graphical representation of a conventional combined-cycle power plant;

Fig. 2 is a graphical representation of a hybrid power plant shown in conjunction with the present inventive subject matter;

Fig. 2A is a graphical representation of a further hybrid power plant shown in conjunction with the present inventive subject matter;

Fig. 3 is a schematic diagram of an embodiment of the present invention;

Fig. 4 is a schematic diagram of an alternate embodiment of the present invention;

Fig. 5 is a schematic diagram of another embodiment of the present invention;

Fig. 5A is a schematic diagram of further embodiment of the present invention;

Fig. 6 is a schematic diagram of a further embodiment of the present invention;

Fig. 7 is a schematic diagram of a still further embodiment of the present invention;

Fig 8 is a schematic diagram of a yet further embodiment of the present invention;

Fig. 9 is a schematic diagram showing an example of the general layout of an embodiment of the present invention;

Fig. 9A is a further schematic diagram showing an example of the general layout of a further embodiment of the present invention;

Fig. 10 is a schematic diagram showing in general an example of an embodiment of the present invention;

Fig. 11 is a schematic diagram showing in general an example of an even additional embodiment of the present invention; and

Fig. 12 is a schematic diagram showing in general a still additional embodiment of the present invention.

Like reference numerals and designations in the various drawings refer to like elements.

DETAILED DESCRIPTION

Turning now to the Figures, Fig. 1 represents a conventional high-efficiency combined-cycle power plant that is well-known in the art. As can be seen from the figure, fuel is supplied to a primary power unit which produces nominal power output. The power output of the primary power unit is generally about 60-80% of the required load. Heat is also exhausted from the primary power unit and supplied to a bottoming power unit, wherein power is produced and supplied to the load. In the conventional combined-cycle power plant as shown in Fig. 1, the ability of the bottoming power unit

to produce electricity depends on the exhausted heat from the primary power unit. In other words, if the primary power unit suddenly stops working, the heat to the bottoming unit also stops and the bottoming power unit no longer is able to function.

The cascading heat from the primary power unit to the bottoming power unit increases the overall efficiency of the combined-cycle power plant in that the waste heat from the primary power unit is put to work by the bottoming power unit. In addition, an optional heater or duct burner is sometimes provided for maintaining the output of the bottoming cycle power unit when the output of the primary power unit drops due to high ambient temperature (the output of the system is sensitive to the air temperature). The duct burner allows for a constant heat flow to be supplied to the bottoming power unit.

The hybrid power generating system of the present inventive subject matter, on the other hand, is graphically represented in Fig. 2. As can be seen from the figure, fuel is supplied to a primary power unit which produces nominal power output. The power output of the primary power unit is generally about 100% of the required load. Heat is also exhausted from the primary power unit and supplied to a secondary power unit, wherein the secondary power unit is kept in hot stand by. In general, the exhausted heat from the primary power unit is sufficient to keep a vaporizer of the secondary power unit operating above its normal operating

temperature and pressure. Further, a burner that operates on the same fuel as the primary power unit is provided to supply heat to the secondary power unit once the primary power unit fails.

The ability of the rejected or exhausted heat from the primary power unit to keep the secondary power unit in hot standby mode contributes to the reliability and redundancy of the present inventive system. It is an important aspect of the present inventive subject matter that the secondary power plant be sized to be able to supply 100% of the electrical load upon failure of the primary power unit. In accordance with the present inventive subject matter, the hybrid power generating system preferably also includes a rotating capacitor that improves its power factor.

Hot standby is defined to mean maintaining the vaporizer of the secondary power unit, a closed cycle vapor turbine (CCVT) which operates according to a Rankine cycle using steam or organic working fluid, at a temperature above its nominal operating temperature.

Idle is defined to mean maintaining the turbine of the CCVT at a rotational speed above its nominal operating rotational speed.

Warm standby is defined to mean maintaining the vaporizer of the CCVT at a temperature at about the same or lower temperature than its nominal operating temperature and maintaining the turbine of the CCVT at a rotational speed at about the same or lower speed than its nominal operating rotational speed. However, in the warm

standby state, the turbine of the CCVT may not be rotated at all. Usually, in the warm standby state, a battery will be used in order to ensure that electric power continues to be supplied to the load at the required level when the primary power unit stops supplying electric power and until the secondary power unit, the CCVT, reaches 100% of the electric power level of the primary power unit and commences supplying electric power to the load at that level.

A further hybrid power generating system of the present inventive subject matter is graphically represented in Fig. 2A. As can be seen from the figure, fuel is supplied to a primary power unit such as a high temperature fuel cell, e.g. a Molten Carbonate Fuel Cell (MCFC) which produces nominal power output. The power output of the primary power unit is generally approximately 85 - 95% of the required load. Heat is also exhausted from the primary power unit and supplied to a secondary power unit e.g. a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle using organic working fluid for producing approximately 5 - 15% of the electric power that is produced by the primary power unit, for a power level preferably ranging from approximately 1 - 40 MW for the hybrid power generating system. Further, a burner that operates on the same fuel as the primary power unit is provided to supply heat to the secondary power unit once the primary power unit fails.

The ability of the rejected or exhausted heat from the primary

power unit to supply heat to the secondary power unit during operation of the primary power unit contributes to the reliability and redundancy of the present inventive system. It is an important aspect of the present inventive subject matter that the secondary power plant be sized to be able to continue to supply 5 - 15% of the power produced by the primary power unit upon failure of the primary power unit. In accordance with the present inventive subject matter, the further hybrid power generating system preferably also includes a rotating capacitor that improves its power factor.

Referring now to Figure 3, reference numeral 5 of Fig. 3 designates an embodiment of the present invention wherein the hybrid ultra reliable power generating system has primary power unit 16 and a secondary power unit that is a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle using steam or organic working fluid and is maintained in hot standby by the exhaust gases of primary power unit 16.

Fuel is supplied to the primary power unit 16 by fuel supply line 14 via fuel valve 12. Fuel valve 12 is connected with controller 26. Under normal operating conditions fuel valve 12 is open, allowing fuel to be supplied to primary power unit 16. Hot exhaust gases containing rejected heat of primary power unit 16 are supplied to vaporizer 58 by primary power unit exhaust line 20 where heat from the hot exhaust gases is transferred to the liquid

in vaporizer **58** via heat exchange device **22**. The exhaust gases from primary power unit **16** heat the working fluid in vaporizer **58** allowing the secondary closed cycle vapor turbogenerator (CCVT) system to remain in hot standby. Cooled exhaust exits vaporizer **58** via exhaust pipe **24**. The rejected heat in the exhaust gases is sufficient to maintain the temperature and pressure of the vaporizer above the normal operating temperature and pressure. The power produced by primary power unit **16** is sensed by sensor **21**. Sensor **21** is connected to controller **26** which monitors power produced by primary power unit **16**. Under normal operating conditions, the power produced by primary power unit **16** is substantially sufficient for supplying the desired load and the power produced by the secondary CCVT system is zero.

In the event of a failure of primary power unit **16**, sensor **21** detects the loss of power. Controller **26** closes fuel valve **12** which supplies fuel to primary power unit **16**. Controller **26** then opens fuel valve **54** which is located on fuel supply line **52**. Fuel supply line **52** supplies fuel to burner **56** of the secondary CCVT system. Controller **26** sends a signal igniting burner **56**. Burner **56** heats vaporizer **58**. Combustion gases produced by burner **56** flow through vaporizer **58** via heat exchanging device **60**, with cooled exhaust gases exiting vaporizer **58** by means of exhaust conduit **62**. Controller **26** sends a signal opening valve **63**, located on the

secondary CCVT system vapor conduit **64**. Vaporized working fluid from vaporizer **58** proceeds through vapor conduit **64** to turbine **66** causing turbine **66** to do work by rotation. Generator **67** coupled to turbine **66** converts the rotational work produced into electric power. The expanded working fluid vapor exhausted from turbine **66** is supplied by expanded working fluid vapor exhaust conduit **68** to condenser **70**. The expanded working fluid vapor is condensed in condenser **70** and the condensate produced is returned to vaporizer **58** through return conduit **71** via pump **72**.

Sensor **75** senses the electric power supplied by the secondary CCVT system, relaying the information to controller **26**. Orifice **74** is provided in order to allow vapor from vaporizer **58** to be supplied to turbine **66** under normal operating condition, i.e., when the secondary CCVT system is not supplying any electrical output to the load. In addition, turbine **66** is rotated during normal operating conditions in order to facilitate faster startup once primary power unit **16** fails. This enables the system to utilize the rotational inertia of turbine **66** when first supplying electricity to the load after failure of the primary power supply.

As has been stated above, it is an important aspect of this embodiment of the present inventive subject matter that the rejected heat from primary power unit **16** maintains vaporizer **58** above its normal operating temperature and pressure. By doing this,

its thermal inertia may be utilized to ensure that vapor is continually produced and supplied to turbine **66**.

In this embodiment of the present inventive subject matter, primary power unit **16** may be, without limitation, a diesel generator (DE or DG), a gas engine generator (GEG), a gas turbine generator (GTG), or a stirling engine generator (STE). In addition, primary power unit **16** supplies AC output to the load.

Referring now to Figure 4, reference numeral **5A** of Fig. 4 designates another embodiment of the present invention. This embodiment of the hybrid ultra reliable power generating system is substantially similar to the embodiment as described with respect to Fig. 3; however, in this embodiment, the output from the primary power unit is alternating current (AC) and therefore may have to be rectified prior to supplying it to the load. The embodiment represented by Fig. 4 has primary power unit **16A** and a secondary power unit that is a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle using steam or organic working fluid and is maintained in hot standby by the exhaust gases of primary power unit **16A**.

Fuel is supplied to the primary power unit **16A** by fuel supply line **14A** via fuel valve **12A**. Fuel valve **12A** is connected with controller **26A**. Under normal operating conditions fuel valve **12A** is open, allowing fuel to be supplied to primary power unit **16A**. Hot exhaust gases containing rejected heat of primary power unit **16A**

are supplied to vaporizer **58A** by primary power unit exhaust line **20A** where heat from the hot exhaust gases is transferred to the liquid in vaporizer **58A** via heat exchange device **22A**. The exhaust gases from primary power unit **16A** heat the working fluid in vaporizer **58A** allowing the secondary closed cycle vapor turbogenerator (CCVT) system to remain in hot standby. Cooled exhaust gases exit vaporizer **58A** via exhaust pipe **24A**. The rejected heat in the exhaust gases is sufficient to maintain the temperature and pressure of the vaporizer above the normal operating temperature and pressure. The power produced by primary power unit **16A** is sensed by sensor **21A**. Sensor **21A** is connected to controller **26A** which monitors power produced by primary power unit **16A**. Under normal operating conditions, the power produced by primary power unit **16A** is substantially sufficient for supplying the desired load and the power produced by the secondary CCVT system is zero. In this embodiment, the electrical output of primary power unit **16A** is in the form of alternating current (AC) electricity. Rectifier **80A** rectifies the AC output of primary power unit **16A** into a direct current (DC) output prior to the same being supplied to the load.

In the event of a failure of primary power unit **16A**, sensor **21A** detects the loss of power. Controller **26A** closes fuel valve **12A** which supplies fuel to primary power unit **16A**. Controller **26A** then opens fuel valve **54A** which is located on fuel supply line **52A**.

Fuel supply line **52A** supplies fuel to burner **56A** of the secondary CCVT system. Controller **26A** sends a signal igniting burner **56A**. Burner **56A** heats vaporizer **58A**. Combustion gases produced by burner **56A** flow through vaporizer **58A** via heat exchanging device **60A**, with exhaust gases exiting vaporizer **58A** by means of exhaust conduit **62A**. Controller **26A** sends a signal opening valve **63A**, located on the secondary CCVT system vapor conduit **64A**. Vaporized working fluid from vaporizer **58A** proceeds through vapor conduit **64A** to turbine **66A** causing turbine **66A** to do work by rotation. Generator **67A** coupled to turbine **66A** converts the rotational work produced into electrical power. In this embodiment, the electrical output of generator **67A** is in the form of alternating current (AC) electricity. Rectifier **82A** rectifies the AC output of generator **67A** into a direct current (DC) output prior to the same being supplied to the load. The expanded vaporized working fluid exhausted from turbine **66A** is supplied by expanded working fluid vapor exhaust conduit **68A** to condenser **70A**. The expanded working fluid vapor is condensed in condenser **70A** and the condensate produced is returned to vaporizer **58A** through return conduit **71A** via pump **72A**.

Orifice **74A** is provided in order to allow vapor from vaporizer **58A** to be supplied to turbine **66A** under normal operating condition, i.e., when the secondary CCVT system is not supplying any electrical output to the load. In addition, turbine **66A** is rotated

during normal operating conditions in order to facilitate faster startup once primary power unit **16A** fails. This enables the system to utilize the rotational inertia of turbine **66A** when first supplying electricity to the load after failure of the primary power supply.

As has been stated above, it is an important aspect of this embodiment of the present inventive subject matter that the rejected heat from primary power unit **16A** maintains vaporizer **58A** at or above its normal operating temperature and pressure. By doing this, its thermal inertia may be utilized to ensure that vapor is continually produced and supplied to turbine **66A**.

In this embodiment of the present inventive subject matter, primary power unit **16A** may be, without limitation, a diesel generator (DE or DG), a gas engine generator (GEG), a gas turbine generator (GTG), or a stirling engine generator (STE).

Referring now to Figure 5, reference numeral **5B** of Fig. 5 designates a further embodiment of the present invention. This embodiment of the hybrid ultra reliable power generating system is substantially similar to the embodiments as described with respect to Figs. 3 and 4; however, in this embodiment, the primary power unit may be a high temperature fuel cell, a solid oxide fuel cell or a molten carbonate fuel cell, and the output is a direct current output. The embodiment represented by Fig. 5 has primary power unit **16B** and a secondary power unit that is a closed cycle vapor

17052/US/03CIP

turbogenerator (CCVT) system which operates according to a Rankine cycle and is maintained in hot standby by the exhaust gases of primary power unit **16B**.

Fuel is supplied to the primary power unit **16B** by fuel supply line **14B** via fuel valve **12B**. Fuel valve **12B** is connected with controller **26B**. Under normal operating conditions fuel valve **12B** is open, allowing fuel to be supplied to primary power unit **16B**. Hot exhaust gases containing rejected heat of primary power unit **16B** are supplied to vaporizer **58B** by primary power unit exhaust line **20B** where heat from the hot exhaust gases is transferred to the liquid in vaporizer **58B** via heat exchange device **22B**. The exhaust gases from primary power unit **16B** heat the working fluid in vaporizer **58B** allowing the secondary closed cycle vapor turbogenerator (CCVT) system to remain in warm standby. Cooled exhaust gases exit vaporizer **58B** via exhaust pipe **24B**. The rejected heat in the exhaust gases is sufficient to maintain the temperature and pressure of the vaporizer at or above the normal operating temperature and pressure. The power produced by primary power unit **16B** is sensed by sensor **21B**. Sensor **21B** is connected to controller **26B** which monitors power produced by primary power unit **16B**. Under normal operating conditions, the power produced by primary power unit **16B** is substantially sufficient for supplying the desired load and the power produced by the secondary CCVT system is zero. In

this embodiment, the electrical output of primary power unit **16B** is in the form of direct current (DC) electricity. Diode **83B** maintains the flow of the DC output of primary power unit **16B** to the load.

In the event of a failure of primary power unit **16B**, sensor **21B** detects the loss of power. Controller **26B** closes fuel valve **12B** which supplies fuel to primary power unit **16B**. Controller **26B** then opens fuel valve **54B** which is located on fuel supply line **52B**. Fuel supply line **52B** supplies fuel to burner **56B** of the secondary CCVT system. Controller **26B** sends a signal igniting burner **56B**. Burner **56B** heats vaporizer **58B**. Combustion gases produced by burner **56B** flow through vaporizer **58B** via heat exchanging device **60B**, with exhaust gases exiting vaporizer **58B** by means of exhaust conduit **62B**. Controller **26B** sends a signal opening valve **63B**, located on the secondary CCVT system vapor conduit **64B**. Vaporized working fluid from vaporizer **58B** proceeds through vapor conduit **64B** to turbine **66B** causing turbine **66B** to do work by rotation. Generator **67B** coupled to turbine **66B** converts the rotational work produced into electrical power. In this embodiment, the electrical output of generator **67B** is in the form of alternating current (AC) electricity. Rectifier **82B** rectifies the AC output of generator **67B** into a direct current (DC) output prior to the same being supplied to the load. The expanded working fluid vapor exhausted from turbine **66B** is supplied by expanded working fluid vapor exhaust

conduit **68B** to condenser **70B**. The expanded working fluid vapor is condensed in condenser **70B** and condensate produced is returned to vaporizer **58B** through return conduit **71B** via pump **72B**.

Orifice **74B** is provided in order to allow vapor from vaporizer **58B** to be supplied to turbine **66B** under normal operating conditions, i.e., when the secondary CCVT system is not supplying any electrical output to the load. In addition, turbine **66B** is rotated during normal operating conditions in order to facilitate faster startup once primary power supply **16B** fails. This enables the system to utilize the rotational inertia of turbine **66B** when first supplying electricity to the load after failure of the primary power supply.

As has been stated above, it is an important aspect of this embodiment of the present inventive subject matter that the rejected heat from primary power unit **16B** maintains vaporizer **58B** above its normal operating temperature and pressure. By doing this, its thermal inertia may be utilized to ensure that vapor is continually produced and supplied to turbine **66B**.

In this embodiment of the present inventive subject matter, primary power unit **16B** may be, without limitation, a high temperature fuel cell, a solid oxide fuel cell (SOFC) or a molten carbonate fuel cell (MCFC).

Referring now to Figure 5A, reference numeral **5b** of Fig. 5A

designates an embodiment of the present invention which is considered at present to be the best mode for carrying out the embodiment. In this embodiment of the hybrid ultra reliable power generating system, the primary power unit may be a high temperature fuel cell, in particular a molten carbonate fuel cell (MCFC), and the output is a direct current output. The embodiment represented by Fig. 5A has primary power unit **16b** and a secondary power unit that is a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle operating on an organic working fluid wherein the working fluid in the vaporizer of the closed cycle vapor turbogenerator (CCVT) system is heated by the exhaust gases of primary power unit **16b**.

Fuel is supplied to the primary power unit **16b** by fuel supply line **14b** via fuel valve **12b**. Fuel valve **12b** is connected with controller **26b**. Under normal operating conditions fuel valve **12b** is open, allowing fuel to be supplied to primary power unit **16b**. Hot exhaust gases containing rejected heat of primary power unit **16b** are supplied to vaporizer **58b** by primary power unit exhaust line **20b** where heat from the hot exhaust gases is transferred to the liquid in vaporizer **58b** via heat exchange device **22b**. The exhaust gases from primary power unit **16b** heat the working fluid in vaporizer **58b** and vaporized working fluid is produced. This vaporized working fluid proceeds through vapor conduit **64b** from

vaporizer **58b** to turbine **66b** causing turbine **66b** to do work by rotation. Generator **67b** coupled to turbine **66b** converts the rotational work produced into electrical power. In this embodiment, the electrical output of generator **67b** is in the form of alternating current (AC) electricity. Rectifier **82b** rectifies the AC output of generator **67b** into a direct current (DC) output prior to the same being supplied to the load. The expanded working fluid vapor exhausted from turbine **66b** is supplied by expanded working fluid vapor exhaust conduit **68b** to condenser **70b**. The expanded working fluid vapor is condensed in condenser **70b** and condensate produced is returned to vaporizer **58b** through return conduit **71b** via pump **72b**. Cooled exhaust gases exit vaporizer **58b** via exhaust pipe **24b**. The rejected heat in the exhaust gases and used in the CCVT is sufficient to produce 5 - 15% of the electric power that is produced by the primary power unit. By using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit.

The power produced by primary power unit **16b** is sensed by sensor **21b**. Sensor **21b** is connected to controller **26b** which monitors power produced by primary power unit **16b**. Under normal operating conditions, the power produced by primary power unit **16b** is substantially sufficient for supplying 85 - 95% of the desired

load and the power produced by the secondary CCVT system is 5 - 15% of the electric power that is produced by the primary power unit. In this embodiment, the electrical output of primary power unit **16** is in the form of direct current (DC) electricity. Diode **83b** maintains the flow of the DC output of primary power unit **16b** to the load. Under such an arrangement, the full power requirements are supplied by the hybrid ultra reliable power generating system.

In the event of a failure of primary power unit **16b**, sensor **21b** detects the loss of power. Controller **26b** closes fuel valve **12b** which supplies fuel to primary power unit **16b**. Controller **26b** then opens fuel valve **54b** which is located on fuel supply line **52b**. Fuel supply line **52b** supplies fuel to burner **56b** of the secondary CCVT system. Controller **26b** sends a signal igniting burner **56b**. Burner **56b** heats vaporizer **58b**. Combustion gases produced by burner **56b** flow through vaporizer **58b** via heat exchanging device **60**, with exhaust gases exiting vaporizer **58b** by means of exhaust conduit **62b**. Vaporized working fluid from vaporizer **58b** proceeds through vapor conduit **64b** to turbine **66b** causing turbine **66b** to do work by rotation. Generator **67b** coupled to turbine **66b** converts the rotational work produced into electrical power. As described above, in this embodiment, the electrical output of generator **67b** is in the form of alternating current (AC) electricity. Rectifier **82** rectifies the AC output of generator **67b** into a direct current (DC)

output prior to the same being supplied to the load. The expanded working fluid vapor exhausted from turbine **66b** is supplied by expanded working fluid vapor exhaust conduit **68b** to condenser **70b**. The expanded working fluid vapor is condensed in condenser **70b** and condensate produced is returned to vaporizer **58** through return conduit **71b** via pump **72b**.

While pump **72b** is shown as not being connected to the turbine shaft of turbine **66b**, if preferred, this pump can be connected to the turbine shaft of turbine **66b** so that such a pump is on the same turbine shaft as generator **67b**.

As has been stated above, it is an important aspect of this embodiment of the present inventive subject matter that primary power unit **16b** may be, without limitation, a high temperature fuel cell, a molten carbonate fuel cell (MCFC) and working fluid of the closed cycle vapor turbogenerator (CCVT) may be an organic working fluid.

Thus, it can be seen from the above description the present embodiment of the invention discloses a primary power unit, such as a high temperature fuel cell, e.g. a molten carbonate fuel cell, producing electric power that is supplied to a load, supplying approximately 85 - 95% of the load, and a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system, which operates according to a Rankine cycle using organic working fluid, that is capable of producing approximately 5 - 15% of the electric

power that is produced by the primary power plant and which is heated by rejected heat of the primary power plant. Consequently, by using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit.

Referring now to Figure 6, reference numeral **5C** of Fig. 6 designates a further embodiment of the present invention. This embodiment of the hybrid ultra reliable power generating system is substantially similar to the embodiment as described with respect to Fig. 5; however, in this embodiment, a battery is provided in order to maintain electrical output to the load while the secondary CCVT is coming on-line. The embodiment represented by Fig. 6 has primary power unit **16C** and a secondary power unit that is a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle using steam or organic working fluid and is maintained in warm standby by the exhaust gases of primary power unit **16C**.

Fuel is supplied to the primary power unit **16C** by fuel supply line **14C** via fuel valve **12C**. Fuel valve **12C** is connected with controller **26C**. Under normal operating conditions fuel valve **12C** is open, allowing fuel to be supplied to primary power unit **16C**. Hot exhaust gases containing rejected heat of primary power unit **16C** are supplied to vaporizer **58C** by primary power unit exhaust line **20C** where heat from the hot exhaust gases is transferred to

the liquid in vaporizer **58C** via heat exchange device **22C**. The exhaust gases from primary power unit **16C** heat the working fluid in vaporizer **58C** allowing the secondary closed cycle vapor turbogenerator (CCVT) system to remain in warm standby. Cooled exhaust gases exit vaporizer **58C** via exhaust pipe **24C**. The rejected heat in the exhaust gases is sufficient to maintain the temperature and pressure of the vaporizer at or even below the normal operating temperature and pressure. The power produced by primary power unit **16C** is sensed by sensor **21C**. Sensor **21C** is connected to controller **26C** which monitors power produced by primary power unit **16C**. Under normal operating conditions, the power produced by primary power unit **16C** is substantially sufficient for supplying the desired load and the power produced by the secondary CCVT system is zero. In this embodiment, the electrical output of primary power unit **16C** is in the form of direct current (DC) electricity. Diode **83C** maintains the flow of the DC output of primary power unit **16C** to the load.

In the event of a failure of primary power unit **16C**, sensor **21C** detects the loss of power. Backup battery **86C** supplies the necessary power to the load via DC bus **87C** until the secondary CCVT is able to come on-line. Controller **26C** then closes fuel valve **12C** which supplies fuel to primary power unit **16C**. Controller **26C** then opens fuel valve **54C** which is located on fuel supply line **52C**. Fuel supply line **52C** supplies fuel to burner **56C** of the secondary

17052/US/03CIP

CCVT system. Controller **26C** sends a signal igniting burner **56C**. Burner **56C** heats vaporizer **58C**. Combustion gases produced by burner **56C** flow through vaporizer **58C** via heat exchanging device **60C**, with exhaust gases exiting vaporizer **58C** by means of exhaust conduit **62C**. Controller **26C** sends a signal opening valve **63C**, located on the secondary CCVT system vapor conduit **64C**. Vaporized working fluid from vaporizer **58C** proceeds through vapor conduit **64C** to turbine **66C** causing turbine **66C** to do work by rotation. Generator **67C** coupled to turbine **66C** converts the rotational work produced into electrical power. In this embodiment, the electrical output of generator **67C** is in the form of alternating current (AC) electricity. Rectifier **82C** rectifies the AC output of generator **67C** into a direct current (DC) output prior to the same being supplied to the load. The expanded working fluid vapor exhausted from turbine **66C** is supplied by expanded working fluid vapor exhaust conduit **68C** to condenser **70C**. The expanded working fluid vapor is condensed in condenser **70C** and condensate produced is returned to vaporizer **58C** through return conduit **71C** via pump **72C**.

The presence of battery **86C** allows for a lag time between the failure of primary power unit **16C** and the coming on-line of the secondary CCVT unit. In this respect, it may not be necessary to maintain the vaporizer temperature and pressure at the operating conditions thereof since the battery will supply the power until

vaporizer **58C** is at its operating temperature and pressure. Preferably, however, the rejected heat from primary power unit **16C** does maintain vaporizer **58C** at its operating temperature and pressure in order to reduce the time in which the battery must supply the power to the load. Likewise, the presence of battery **86C** means that turbine **66C** need not necessarily be rotated at all; however it is preferable to have turbine **66C** rotating in order to reduce the lag time.

In this embodiment of the present inventive subject matter, primary power unit **16C** may be, without limitation, a high temperature fuel cell, a solid oxide fuel cell (SOFC) or a molten carbonate fuel cell (MCFC).

While the use of a battery (usually a relatively small one) is described with reference to the present embodiment, such use may take place with any other embodiment herein described wherein the secondary CCVT will be maintained in warm standby rather than hot standby.

Referring now to Figure 7, reference numeral **5D** of Fig. 7 designates a further embodiment of the present invention. This embodiment of the hybrid ultra reliable power generating system is substantially similar to the embodiment as described with respect to Figs. 3 and 4; however, in this embodiment, the primary power unit may be any power unit previously described, and in lieu of an orifice for allowing vapor to be supplied to the turbine during

normal operation, a bypass conduit supplies vapor to only one or several nozzle(s) of the turbine. The embodiment represented by Fig. 7 has primary power unit **16D** and a secondary power unit that is a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle using steam or organic working fluid and is maintained in hot standby by the exhaust gases of primary power unit **16D**.

Fuel is supplied to the primary power unit **16D** by fuel supply line **14D** via fuel valve **12D**. Fuel valve **12D** is connected with controller **26D**. Under normal operating conditions fuel valve **12D** is open, allowing fuel to be supplied to primary power unit **16D**. Hot exhaust gases containing rejected heat of primary power unit **16D** are supplied to vaporizer **58D** by primary power unit exhaust line **20D** where heat from the hot exhaust gases is transferred to the liquid in vaporizer **58D** via heat exchange device **22D**. The exhaust gases from primary power unit **16D** heat the working fluid in vaporizer **58D** allowing the secondary closed cycle vapor turbogenerator (CCVT) system to remain in hot standby. Exhaust gases of primary power unit **16D** exit vaporizer **58D** via exhaust pipe **24D**. The rejected heat in the exhaust gases is sufficient to maintain the temperature and pressure of the vaporizer above the normal operating temperature and pressure. The power produced by primary power unit **16D** is sensed by sensor **21D**. Sensor **21D** is

connected to controller **26D** which monitors power produced by primary power unit **16D**. Under normal operating conditions, the power produced by primary power unit **16D** is substantially sufficient for supplying the desired load and the power produced by the secondary CCVT system is zero. In this embodiment, the electrical output of primary power unit **16D** is in the form of direct current (DC) electricity. Diode **83D** maintains the flow of the DC output of primary power unit **16D** to the load.

In the event of a failure of primary power unit **16D**, sensor **21D** detects the loss of power. Controller **26D** closes fuel valve **12D** which supplies fuel to primary power unit **16D**. Controller **26D** then opens fuel valve **54D** which is located on fuel supply line **52D**. Fuel supply line **52D** supplies fuel to burner **56D** of the secondary CCVT system. Controller **26D** sends a signal igniting burner **56D**. Burner **56D** heats vaporizer **58D**. Combustion gases produced by burner **56D** flow through vaporizer **58D** via heat exchanging device **60D**, with exhaust gases exiting vaporizer **58D** by means of exhaust conduit **62D**. Controller **26D** sends a signal opening valve **63D**, located on the secondary CCVT system vapor conduit **64D**. Vaporized working fluid from vaporizer **58D** proceeds through vapor conduit **64D** to turbine **66D** causing turbine **66D** to do work by rotation. Generator **67D** coupled to turbine **66D** converts the rotational work produced into electrical power. In this embodiment, the electrical output of

generator **67D** is in the form of alternating current (AC) electricity. Rectifier **82D** rectifies the AC output of generator **67D** into a direct current (DC) output prior to the same being supplied to the load. The expanded working fluid vapor exhausted from turbine **66D** is supplied by expanded working fluid vapor exhaust conduit **68D** to condenser **70D**. The expanded working fluid vapor is condensed in condenser **70D** and condensate produced is returned to vaporizer **58D** through return conduit **71D** via pump **72D**.

Bypass conduit **87D** is provided in order to allow vapor from vaporizer **58D** to be supplied to one or several nozzle(s) of turbine **66D** under normal operating conditions, i.e., when the secondary CCVT system is not supplying any electrical output to the load. In addition, turbine **66D** is rotated during normal operating conditions in order to facilitate faster startup once primary power supply **16D** fails. Preferably, turbine **66D** is rotated at a speed faster than the normal operating speed in order that its rotational inertia be utilized when first supplying electricity to the load after failure of the primary power supply. The use of bypass conduit **87D** for supplying vapor from vaporizer **58D** to one or several of the nozzle(s) of turbine **66D** facilitates the operation or idling of the turbine at a rotational speed above its nominal operating speed.

As has been stated above, it is an important aspect of this embodiment of the present inventive subject matter that the

rejected heat from primary power unit **16D** maintain vaporizer **58D** at or above its normal operating temperature and pressure. By doing this, its thermal inertia can be utilized to ensure that vapor is continually produced and supplied to turbine **66D**.

In this embodiment of the present inventive subject matter, primary power unit **16D** may be any of the previously discussed power units including, without limitation, a high temperature fuel cell, a solid oxide fuel cell (SOFC), a molten carbonate fuel cell (MCFC), a diesel generator (DE or DG), a gas engine generator (GEG), a gas turbine generator (GTG), or a stirling engine generator (STE).

Referring now to Figure 8, reference numeral **5E** of Fig. 8 designates a further embodiment of the present invention considered at present the best mode for carrying out the present embodiment. This embodiment of the hybrid ultra reliable power generating system is substantially similar to the embodiment as described with respect to Fig. 7; however, in this embodiment, the condenser may be water-cooled or air-cooled, and the condensate pump is on the same shaft as the generator of the CCVT. The embodiment represented by Fig. 8 has primary power unit **16E** and a secondary power unit that is a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle using steam or organic working fluid and is maintained in hot standby by the exhaust gases of primary power unit **16E**.

Fuel is supplied to the primary power unit **16E** by fuel supply line **14E** via fuel valve **12E**. Fuel valve **12E** is connected with controller **26E**. Under normal operating conditions fuel valve **12E** is open, allowing fuel to be supplied to primary power unit **16E**. Hot exhaust gases containing rejected heat of primary power unit **16E** are supplied to vaporizer **58E** by primary power unit exhaust line **20E** where heat from the hot exhaust gases is transferred to the liquid in vaporizer **58E** via heat exchange device **22E**. The exhaust gases from primary power unit **16E** heat the working fluid in vaporizer **58E** allowing the secondary closed cycle vapor turbogenerator (CCVT) system to remain in hot standby. Cooled exhaust gases exit vaporizer **58E** via exhaust pipe **24E**. The rejected heat in the exhaust gases is sufficient to maintain the temperature and pressure of the vaporizer above the normal operating temperature and pressure. The power produced by primary power unit **16E** is sensed by sensor **21E**. Sensor **21E** is connected to controller **26E** which monitors power produced by primary power unit **16E**. Under normal operating conditions, the power produced by primary power unit **16E** is substantially sufficient for supplying the desired load and the power produced by the secondary CCVT system is zero. In this embodiment, the electrical output of primary power unit **16E** is in the form of direct current (DC) electricity. Diode **83E** maintains the flow of the DC output of primary power unit **16E** to the load.

In the event of a failure of primary power unit **16E**, sensor **21D** detects the loss of power. Controller **26E** closes fuel valve **12B** which supplies fuel to primary power unit **16E**. Controller **26E** then opens fuel valve **54E** which is located on fuel supply line **52E**. Fuel supply line **52E** supplies fuel to burner **56E** of the secondary CCVT system. Controller **26E** sends a signal igniting burner **56E**. Burner **56E** heats vaporizer **58E**. Combustion gases produced by burner **56E** flow through vaporizer **58E** via heat exchanging device **60E**, with exhaust gases exiting vaporizer **58E** by means of exhaust conduit **62E**. Controller **26E** sends a signal opening valve **63E**, located on the secondary CCVT system vapor conduit **64E**. Vaporized working fluid from vaporizer **58E** proceeds through vapor conduit **64E** to turbine **66E** causing turbine **66E** to do work by rotation. Generator **67E** coupled to turbine **66E** converts the rotational work produced into electrical power. In this embodiment, the electrical output of generator **67E** is in the form of alternating current (AC) electricity. Rectifier **82E** rectifies the AC output of generator **67E** into a direct current (DC) output prior to the same being supplied to the load. The expanded working fluid vapor exhausted from turbine **66E** is supplied by expanded working fluid vapor exhaust conduit **68E** to condenser **70E**. The expanded working fluid vapor is condensed in condenser **70E** and condensate produced is returned to vaporizer **58E** through return conduit **71E** via pump **72E**. In this

embodiment, pump **72E** is on the same turbine shaft as generator **67E**.

Bypass conduit **87E** is provided in order to allow vapor from vaporizer **58E** to be supplied to one nozzle of turbine **66E** under normal operating conditions, i.e., when the secondary CCVT system is not supplying any electrical output to the load. In addition, turbine **66E** is rotated during normal operating conditions in order to facilitate faster startup once primary power supply **16E** fails. Preferably, turbine **66E** is rotated at a speed faster than the normal operating speed in order that its rotational inertia can be utilized when first supplying electricity to the load after failure of the primary power supply. Also here, the use of bypass conduit **87E** for supplying vapor from vaporizer **58E** to one or several nozzle(s) of turbine **66E** facilitates the operation or idling of the turbine at a rotational speed above its nominal operating speed.

As has been stated above, it is an important aspect of this embodiment of the present inventive subject matter that the rejected heat from primary power unit **16E** maintains vaporizer **58E** above its normal operating temperature and pressure. By doing this, its thermal inertia can be utilized to ensure that vapor is continually produced and supplied to turbine **66E**.

In this embodiment of the present inventive subject matter, primary power unit **16E** may be any of the previously discussed power units including, without limitation, a high temperature fuel cell,

a solid oxide fuel cell (SOFC), a molten carbonate fuel cell (MCFC), a diesel generator (DE or DG), a gas engine generator (GEG), a gas turbine generator (GTG) or a stirling engine generator (STE).

It should be pointed out that, in this embodiment, if the amount of rejected heat contained in the exhaust gases of primary power unit **16E** exceeds more than that which is required by using the secondary CCVT to produce 5-10%, or even more, of the power needed to supply all the load requirement, then, if preferred, secondary CCVT system can produce electric power also during normal operating conditions. In such a case, turbine **66E** is operated by vapor supplied through line **87E** to one nozzle thus causing turbine **66E** to do work by rotation. Generator **67E** coupled to turbine **66E** converts the rotational work produced into electric power that is supplied to the load via rectifier **82E** converting the alternating (AC) output into a direct current (DC) output. By such operation, the efficiency of the system is improved during normal operation. In this option, when sensor **21E** senses a loss in power from primary power unit **16E**, controller **26E** closes fuel valve **12B** which supplies fuel to primary power unit **16E**. Controller **26E** then opens fuel valve **54E** which is located on fuel supply line **52E**. Fuel supply line **52E** then supplies fuel to burner **56E** of the secondary CCVT system. Controller **26E** sends a signal igniting burner **56E**. Burner

56E heats vaporizer **58E**. Combustion gases produced by burner **56E** flow through vaporizer **58E** via heat exchanging device **60E**, with exhaust gases exiting vaporizer **58E** by means of exhaust conduit **62E**. Controller **26E** sends a signal opening valve **63E**, located on the secondary CCVT system vapor conduit **64E**. Vaporized working fluid from vaporizer **58E** proceeds now through vapor conduit **64E** to turbine **66E** causing turbine **66E** to continue to do work by rotation. Generator **67E** coupled to turbine **66E** converts the rotational work produced into electric power that is supplied to the load via rectifier **82E** which converts the alternating current (AC) output to a direct current (DC) output. Now secondary CCVT supplies 100% of the power to the load. The expanded working fluid vapor exhausted from turbine **66E** is supplied by expanded working fluid vapor exhaust conduit **68E** to condenser **70E**. The expanded working fluid vapor is condensed in condenser **70E** and condensate produced is returned to vaporizer **58E** through return conduit **71E** via pump **72E**.

While this option is described with reference to the embodiment described with reference to Figure 8, it can be applied to the embodiments of the invention described herein.

Thus, it can be seen from the above description the present invention discloses a primary power unit producing electric power that is supplied to a load and a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system, which operates

according to a Rankine cycle using steam or organic working fluid, that is capable of producing 100% of the electric power that is produced by the primary power plant and which is heated in hot standby by rejected heat of the primary power plant. Fig. 9 shows an example of a general layout diagram of such a power generating system. The vaporizer of the CCVT is maintained during hot standby at a temperature above its normal operating temperature and the vapor turbine of the CCVT is maintained preferably at idle during hot standby at a rotating speed above its normal rotating speed. As shown, preferably, the CCVT includes a burner that combusts the same fuel as the primary power plant and supplies sufficient heat so that the CCVT produces 100% of power produced by said primary power plant to the load once the primary power plant stops operation.

Furthermore, Fig. 9A shows an example of a general layout diagram of a power generating system described with reference to Fig. 5A. The vaporizer of the CCVT is operated by heat present in the hot exhaust gases of MCFC. As shown, preferably, the CCVT includes a burner that combusts the same fuel as the primary power plant and supplies sufficient heat so that the CCVT continues to produce approximately 5 -15% of electric power produced by said primary power plant to the load once the primary power plant stops operation.

In general, without limitation, an example of the power levels

of the combined hybrid system is in the range of 1 - 40 MW.

Thus, the present embodiment of the invention as herein described provides a high efficiency and reliable power generating system which is attainable since the selected primary power units, e.g. MCFC, described herein achieve high efficiency levels and the secondary power units CCVT are adapted for producing power concurrently with the primary power unit is operating by using the heat present in the hot exhaust gases of the primary power unit of a corresponding primary power unit, thereby resulting in a hybrid power generating system having a higher efficiency level than that of the primary power unit. In addition, the cost (per kW) of the hybrid power generating system is lower than that of the primary power unit. Furthermore, both the MCFC and CCVT systems have relatively long life of approximately 20 - 30 years so that the power generating system will also have a relatively long life. Moreover, the secondary power unit CCVT provides this system with an ultra high level of reliability since it will continue to generate electricity upon power outage of the primary power unit. Consequently, the number of required maintenance visits may be decreased relative to diesel generator systems. By using the system and method of the present embodiment, maintenance visits may be planned in advance during normally acceptable working hours, rather than during weekends, nighttime or other inconvenient times, as carried out heretofore with prior art systems. Whereas relatively

long periods of standby operation and unreliable startups, and consequently frequent maintenance visits, are characteristic of diesel generator systems, maintenance visits of the system of the present embodiment are not imperative during power outage of the primary power unit, since the secondary power unit CCVT will continue to operate and supply some of the electric power needed by the load. As maintenance is carried out to the primary power unit, operating costs consist only of usage of fuel for operating the secondary power unit.

In addition, it should be noted that while in the above description, one primary power unit and one closed cycle vapor turbine (CCVT) are described in the each of the embodiments, more primary power units and more closed cycle vapor turbines (CCVT's) can be used in a single arrangement (see Fig. 10). However, preferably, in each arrangement, there will be usually one more primary power unit than the number closed cycle vapor turbines (CCVT's) used and Fig. 10 shows an example of such an arrangement.

Additionally, while the embodiments herein described describe a system wherein heat contained in the heat rejected from the primary power unit is utilized to maintain the secondary CCVT in hot standby or warm standby, other heat sources can also be used. Figure 11 shows an example of such a system wherein heat from hot water or fluid from engine cooling system 82H of primary power unit 16H is also utilized as a heat source for secondary CCVT 80H to

maintain it in hot standby or warm standby.

Furthermore, while the embodiments described above mention a separate electric generator for use together with the CCVT, if preferred, when the primary power unit comprises a diesel generator (DE or DG) a gas engine generator (GEG), a gas turbine generator (GTG), or a stirling engine generator (STE), common electrical generator 67I can be used for the primary power unit and the CCVT (see Fig. 12). In such a case, automatic clutch or selectively operable coupling 84I can be used to disconnect the output of primary power unit 16I mover from generator 67I when the primary power unit stops operation.

Thus, the present invention as herein described provides a high efficiency and reliable power generating system. This is because the primary power units described herein achieve high efficiency levels while the secondary CCVT provides this system with an ultra high level of reliability. Such a system provides the opportunity to decrease the critical feature of maintenance visits so common in diesel generator systems. By using the system and methods of the present invention, maintenance visits can be planned in a much calmer manner. This is because now it will not be so critical to reach the system when the primary power unit stops since the secondary CCVT will continue to operate and supply full or 100% of the electric power needed by the load even when the primary power unit has stopped. One will only have to pay for the

fuel to operate the secondary CCVT until maintenance is carried out to the primary power unit. Consequently, such maintenance visits can now be carried during weekdays and during normal working hours rather than on weekends or during the night or other inconvenient times as when using the system of the prior art.

Furthermore, when a high temperature fuel cell, solid oxide fuel cell (SOFC) or a molten carbonate fuel cell (MCFC) are used as herein described, cartridges of the fuel cells themselves or stacks thereof can be advantageously used in accordance with the present invention. By using such fuel cell cartridges, only the cartridges need to be replaced rather than the whole fuel cell system when maintenance has to be carried out to the above mentioned fuel cell primary power unit. Such replacement cartridges will decrease the cost of maintenance for these systems and also facilitate it.

It is believed that the advantages and improved results furnished by the method and apparatus of the present invention are apparent from the foregoing description of the invention. Various changes and modifications may be made without departing from the spirit and scope of the invention as described in the claims that follow.